Technical Bulletin 115 Reprinted March 1938

A Study of the Body and Texture of Butter

S. T. Coulter and W. B. Combs
Division of Dairy Husbandry

University of Minnesota
Agricultural Experiment Station

A Study of the Body and Texture of Butter

S. T. Coulter and W. B. Combs
Division of Dairy Husbandry

University of Minnesota
Agricultural Experiment Station

CONTENTS

A Study of the Body and Texture of Butter

S. T. Coulter and W. B. Combs

INTRODUCTION

On the principal markets of the world butter is graded according to its flavor, body and texture, color, salt, and the appearance of the package. The flavor of butter has received the most critical attention. At one time considerable importance was attached to the body and texture of butter. In recent years, however, there has developed a tendency, particularly in commercial grading, to judge less critically the defects in body and texture when their occurrence could not be explained. The butter submitted at the national exhibit, sponsored by the National Creamery Buttermakers' Association, frequently has been criticized for possessing a faulty body and texture. At the 1935 exhibit of this association, 19 per cent of the 338 lots of butter entered in the fresh butter contest were cut in score one-half point or more because of unsatisfactory body, and an additional 17 per cent of the entries were criticized. Among the most common defects in body and texture are those frequently referred to as "sticky" and "crumbly." It is with these body defects that this publication is concerned.

The studies on the body of butter herein reported were begun in 1926. Initial work was prompted by the fact that a considerable quantity of the butter received at the plant of one of the large butter marketing organizations in Minnesota was graded as crumbly.

A survey of the existing situation revealed that more or less butter graded as crumbly was received each winter, but that the defect was not common in summer butter. From November 20, 1926 to March 9, 1927, 373,464 pounds or 2.8 per cent of the butter graded by Federal-State butter graders at one plant was graded as "crumbly." This does not mean that only 2.8 per cent of the butter graded was crumbly, but that only this quantity was considered defective enough to warrant a cut in score. The defect was not limited to the butter manufactured by a few creameries. At least one churning of butter from each of 146 creameries was graded as crumbly during the period covered by the survey.

The Composition of the Butterfat

Since the occurrence of the defect was common only during the winter season, it seemed probable that the composition of the butterfat was a factor. Fat constants, including the iodine number, the Reichert-

Meissl number, and the melting point, were determined for butterfat from butter that was graded crumbly, and from butter that was not cut in score, from the same creamery. Samples were obtained from six creameries in widely separated parts of the state. The mean values for the fat constants of the "crumbly" and normal samples are shown in Table 1.

Table 1.—Mean Values for Fat Constants of "Crumbly" and Normal Samples*

Fat constant	Butterfat from butter graded "crumbly"	Butterfat from butter graded normal
Iodine number	29.72	30.48
Reichert-Meissl number	28.15	28.15
Melting point	33.78	33.33

* These analyses were supervised by Dr. L. S. Palmer, Division of Agricultural Biochemistry, University of Minnesota.

The iodine number of the butterfat from the crumbly samples is slightly lower and the melting point slightly higher than the same values for the butterfat from the normal samples. These differences are so slight that they can be of only minor significance.

That winter butter in general is harder than summer butter is of course due to differences in the composition of the fat. The close inverse proportionality between the iodine number of the butterfat and the hardness of the butter has been shown by Haglund, Wode, and Olssón (1), and Coulter and Hill (2). The iodine number of mixed herd butterfat ranges in value from 40 to 45 in June and July to 29 to 30 in December and January. This statement is substantiated by results secured in Denmark by Kilde and Winther (3), in Germany by Peter and Kron (4) and Peters (5), in France by Polonovski and Thomas (6), and in the United States by Coulter and Combs (7). The results reported by these different workers are surprisingly uniform and must be considered as typical of the values for butterfat produced under normal feed conditions.

The natural hardness of winter butter suggests that this is a contributory factor to the occurrence of "crumbly" butter.

The Stage of Lactation of the Cows

A number of churnings were made during the winter of 1927-28 and again during the winter of 1928-29 from cream produced by cows in the University herd which had been in milk 10 months or longer. The butter from these churnings was compared with that manufactured under the same conditions from cream produced by cows in normal lactation. The body of practically all of the butter was judged to be satisfactory and in no case was that from the "stripper" cows more crumbly than that from the normal cows.

tation. The body of practically all of the butter was judged to be satisfactory and in no case was that from the "stripper" cows more crumbly than that from the normal cows.

The Use of Frozen Cream

A large number of churnings of frozen cream have been made at University Farm. In no case has butter made from frozen cream been judged to be more crumbly than butter from unfrozen cream manufactured under the same conditions.

The Manufacturing Methods Used

During the summer months it is a common practice in this section to wash the butter with water at the temperature at which it comes from the well. This temperature usually will be from 8.9° to 10°C. (48° to 50°F.). The almost universal practice during the winter months has been to raise the temperature of the wash water to approximately that of the butter. This temperature usually will be from 12.22° to 15.56°C. (54° to 60°F.) The prevalent opinion among buttermakers and butter graders, and an opinion frequently expressed in the trade papers, is that the so-called "crumbly" butter is caused by the use of too cold wash water.

Numerous churnings were made at University Farm during the period from 1927 to 1929 comparing the effect of the use of cold and warm wash water on the body of butter. These data will not be reported in detail since the results were inconclusive. Crumbly-bodied butter was not consistently produced by the use of cold wash water. The data definitely indicated, in fact, that defective-bodied butter was no more likely to be produced by washing with extremely cold wash water than by washing with water at normal temperatures. The data, however, were not consistent enough to justify expression of this opinion in view of the common belief to the contrary. Later work initiated with a better understanding of the factors involved produced more satisfactory results.

Method of Examining the Butter

From trials conducted, it soon became apparent that the temperature of the trier as well as the temperature and age of the butter were of prime importance in detecting the so-called "crumbly" body. Perfectly normal-bodied butter could be made to show a ragged boring condition if the trier were cold enough, or if the butter was examined at a low temperature. Conversely, a smooth plug could be drawn from butter with a very defective body if the trier or the butter were sufficiently warm. These facts are clearly demonstrated in Figures 1 and 2.

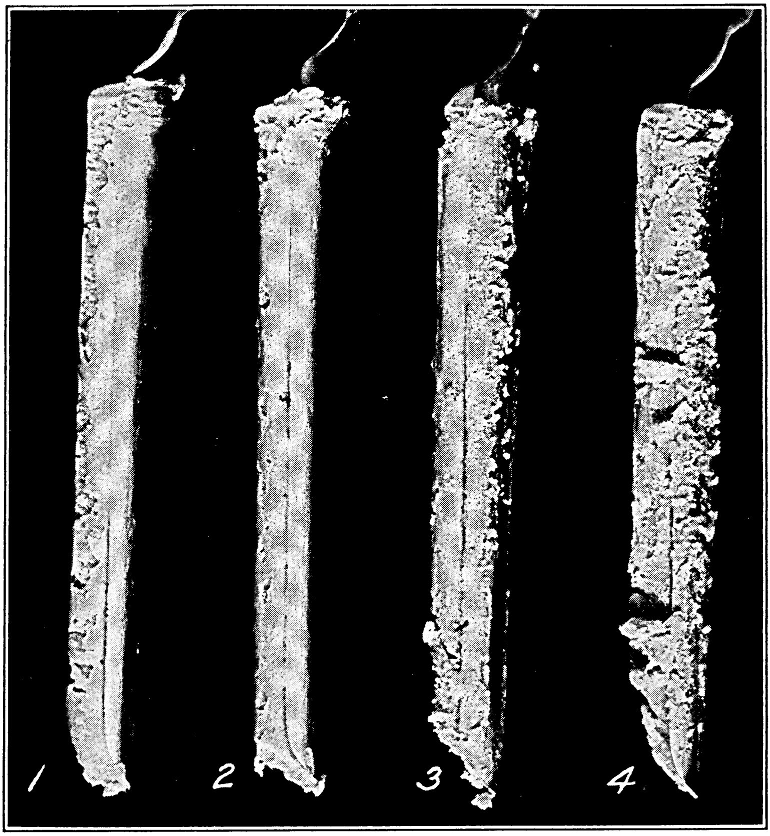

FIG. 1. IF THE TEMPERATURE OF THE TRIER, OR BUTTER, OR BOTH, IS LOW, EVEN NORMAL-BODIED BUTTER MAY BE JUDGED AS CRUMBLY

(1) Butter 50° F., trier 50° F.; (2) butter 50° F., trier 35° F.; (3) butter 35° F., trier 50° F.; (4) butter 35° F., trier 35° F.

Butter examined within a day or two of manufacture will frequently exhibit a ragged boring condition, whereas it may appear to have a normal body if examined after it has become thoroly firm. On several occasions the authors were asked to examine butter previously graded as crumbly, only to find it entirely normal. Obviously the butter was too fresh at the time of the original examination.

Renaming the Defect

It soon became apparent that "crumbly" was not the correct designation for the defect in question. As may be seen from a study of the third and fourth triers of butter in Figure 2, butter exhibiting this defect is not only crumbly in that the particles lack cohesion, but it is also sticky, as attested by the manner in which it adheres to the trier. The defect should perhaps more properly be called "sticky" or "sticky crumbly" to distinguish it from typically crumbly butter, an illustration of which is shown in Figure 3. The butter to the right in Figure 3, was churned from the cream from an individual cow. Altho the iodine number of the fat was not determined, it must have been low. The butter was very hard and, when crushed, shattered into fragments as shown. Despite its crumbly or friable character, a "clean" plug could be drawn from this butter with a trier. The manner of crushing of a normal-

FIG. 2. CRUMBLINESS IN BUTTER MAY NOT BE DETECTED IF THE TEMPERATURE OF THE TRIER, OR BUTTER, OR BOTH, IS ABNORMALLY HIGH

(1) Butter 70° F., trier 70° F.; (2) butter 50° F., trier 70° F.; (3) butter 35°F.. trier 70° F.; (4) butter 35° F., trier 50° F.

bodied butter is shown for contrast. This type of butter is probably not common.

Since the winter of 1926-27 comparatively little of the butter graded at the plant at which the original observations were made has been graded as "crumbly." This is probably due in part to the use of better manufacturing methods by the operators, but principally to a greater tolerance on the part of the butter graders. The use of warm

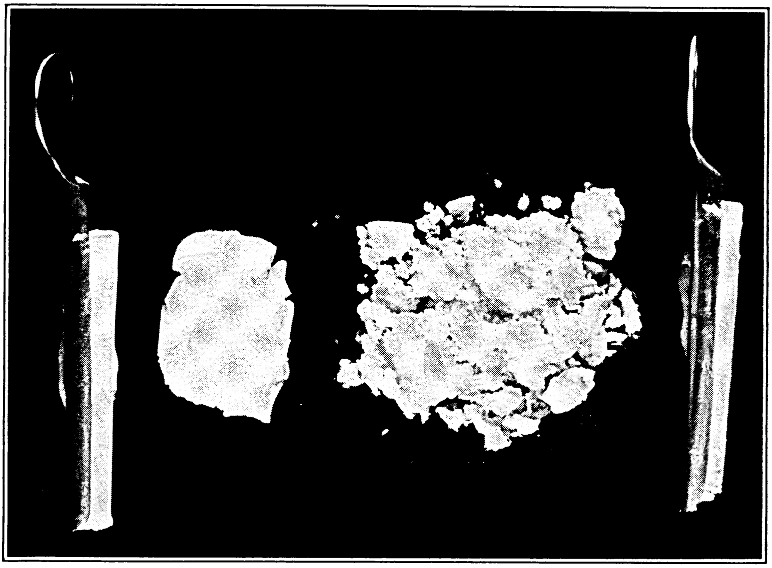

FIG. 3. TRIER SAMPLE AND CRUSHED CUBE FROM NORMAL BUTTER (LEFT) AND CRUMBLY BUTTER

triers has facilitated the grading and tended to minimize the defect. This greater tolerance on the part of the grader may probably be attributed to a realization that this defect could not be eliminated in winter butter with the information at that time available to the operator and to a further realization that if the defect was not too serious it did not affect the salability of the butter.

REVIEW OF LITERATURE

Recent work, especially in Europe, has shown that the hardness of butter may be affected appreciably by the manufacturing methods used. Haglund, Wode and Olsson (1), and later Wode (8) have reported the results of extensive experiments. Their work was done almost entirely with ripened cream butter, so it is not strictly applicable to manufacturing conditions as they exist generally in this section of the country.

They used a modification of the Perkins (9) method for determining the hardness of the butter. The extent to which the cream was cooled was found to influence materially the hardness of the butter. The lower the temperature at which the cream was held, the harder the butter. Likewise, chilling the cream before or after ripening produced a harder butter than ripening the cream without chilling. The rate at which the cream was cooled or heated also affected the hardness of the butter. Rapid cooling of the cream below the ripening temperature, or rapid heating of chilled cream to the churning temperature resulted in harder butter. Cooling the butter particles before working by the use of cold wash water was found to have a variable effect, depending on the iodine number of the butterfat. If the iodine number of the butterfat was low, cooling the butter particles decreased the hardness of the butter; if the iodine number of the butterfat was high, the hardness was increased.

Mohr and Oldenburg (10) found that the consistency of the butter as well as the hardness could be affected by variations in the manufacturing procedure. They report data showing that by the use of wash water with a temperature of under 4°C. (39.2°F.), the resistance of the butter to crushing and to cutting with a wire could be much reduced as compared with butter made with wash water at temperatures from 14 to 20°C. (57.2 to 68°F.).

By washing the butter with water at a low temperature, the occurrence of crumbly- or friable-bodied butter could be avoided. They recommended low-temperature wash water during the winter to reduce the firmness and improve the body of the butter, and high-temperature wash water during the summer to increase the firmness. They report, tho they do not present data in substantiation, that to avoid a friable consistency of butter the cream should not be cooled to a temperature lower than necessary. Excessive cooling of the cream was stated to produce friable butter despite the use of low-temperature wash water. Mohr and Oldenburg emphasized the necessity that the churn workers be in good condition. They found that replacing worn rolls in some churns brought improvement in the body of the butter. They found also that the speed of the workers affected the body of the butter. Workers operating at a speed in excess of 40 revolutions per minute produced a more friable butter than workers operating at a lower speed.

A paper published anonymously (11) reports the results of work by Storgard at the Finnish testing station for milk production at Jokioinen, Finland. This work largely confirms that of Mohr and Oldenburg, (10). The use of wash water with a low temperature was found to improve the body of winter butter. This was especially true if the cream after pasteurization had been subjected only to moderate cooling.

Excessive cooling of the cream before churning and the use of high-temperature wash water produced brittle butter from butterfat with a low iodine number. Overworking of the butter was found to make a poorer consistency, irrespective of the working temperature or speed of the workers.

Eckardt (12), tho not reporting data, suggests a different procedure for the avoidance of crumbly or friable butter during the winter months. The cream is cooled to a moderate temperature only, and the butter is washed with water 3 to 4°C. or 5.4 to 7.2°F. higher than the churning temperature. After washing, the butter granules are worked just enough to bring the butter into a roll. Completion of the working is then delayed until the butter has an opportunity to firm.

Boss (13) describes a method for the prevention of crumbly butter in which the cream is held at a high temperature (about 20°C. [68°F.]), churned at a high temperature (17 to 18°C. [62.6 to 64.4°F.]), and also washed at a relatively high temperature, 16°C. (60.8°F.).

Richardson and Abbott (14) report experiments with "sticky" butter manufactured in the western section of the United States. Their work shows that this defect occurs principally where butter is manufactured from butterfat secreted by cows restricted to a diet of alfalfa hay. Feeding experiments indicated that tho the iodine number of the butterfat produced by cows on a sole diet of alfalfa hay was slightly increased, the Reichert-Meissl value of the butterfat was markedly decreased. The abnormal character of the butter was therefore associated with the low Reichert-Meissl value of the butterfat. Coulter and Hill (2) have shown that the hardness of the butterfat varies not only with the iodine number of the butterfat, but also with the Reichert-Meissl number of the fat. Whether butterfat hard because of a reduced content of volatile fatty acids (low Reichert-Meissl number) would produce the same type of butter as butterfat with a normal content of volatile fatty acids but hard because of a low percentage of unsaturated fatty acids (low iodine number) is not known. Richardson and Abbott were able to improve the body of this butter by control of the manufacturing procedure. They recommend that the cream after pasteurization, or if the cream has previously been cooled, after warming to 48.89°C. (120°F.), be cooled as rapidly as possible to the churning temperature and be churned immediately at such a temperature that the butter will come in 50 to 60 minutes under normal churning conditions. If the resulting butter is normally firm, use wash water at a temperature of 1.7 to 2.2°C. or 3 to 4°F. below that of the buttermilk; if soft, as much as 5.5°C. or 10°F. below the temperature of the buttermilk.

Valentine and Sargent (15) found that the rate at which the cream was cooled influenced the firmness and spreadability of New Zealand butter. Many of the New Zealand butter factories cool the cream over a direct expansion cooler to the churning temperature. This results in very rapid cooling. These workers report that cream that is cooled in this manner to a very low temperature (under 4.40°C. [40°F.]) produces butter with a hard flinty body. Such butter when sampled at a low temperature after storage will have a short suety body, will be pale in color and without lustre, and at a high temperature will probably be "salvy." Sargent (15) describes a method for determining the spreadability of butter.

EXPERIMENTAL METHODS

A large number of churnings were made using laboratory equipment. For churning, a battery of four "Daizy" type glass churns was used. This equipment was the same as that used by Coulter and Combs (7). The butter at first was worked by hand, using butter ladles, later a small hand-driven butter worker (Fig. 4) was used. To supplement the laboratory churnings, a number of churnings were made using standard type churns having a capacity of 500 pounds of butter. Much more uniform results were secured with the large churns than with the lab-

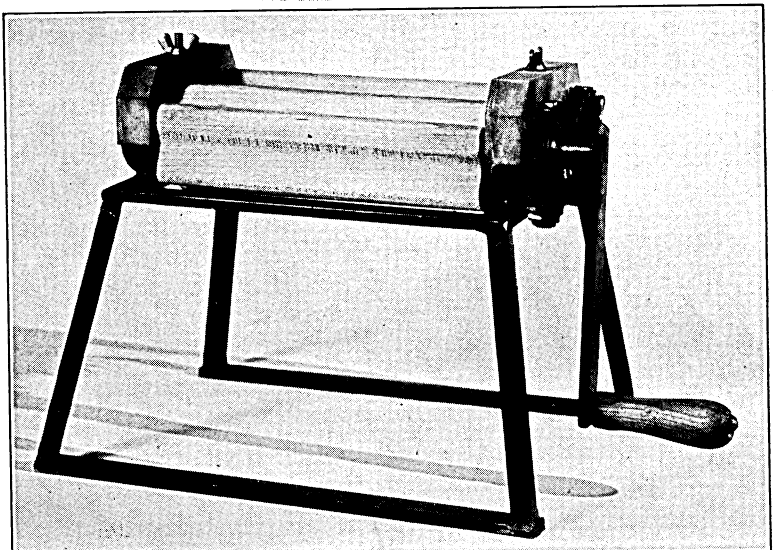

FIG. 4. HAND-DRIVEN BUTTER-WORKER USED IN EXPERIMENTAL CHURNINGS

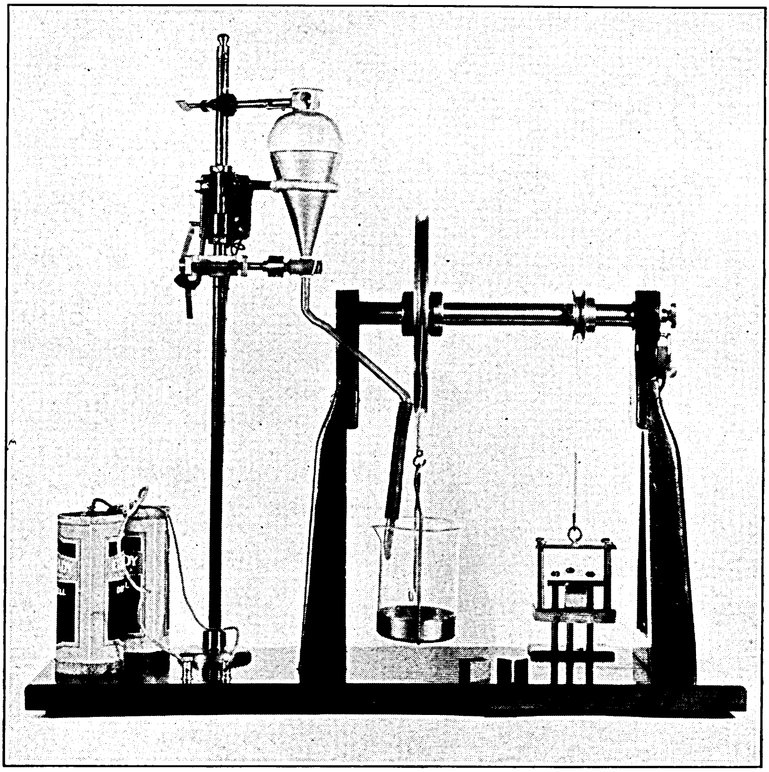

FIG. 5. APPARATUS USED FOR HARDNESS DETERMINATIONS

oratory equipment. This was especially true when the butter was worked with ladles. Therefore, of the data secured with the laboratory equipment only that portion is reported in which the hand-driven worker was used. All of the data, however, support the conclusion drawn.

The butter in the laboratory churnings was washed twice with wash water of the desired temperature, using each time the same volume of wash water as of cream churned. Each portion of the wash water was left on the butter granules for five minutes before draining. The butter in the commercial churnings was washed once with water of the desired temperature, using the same volume of water as of cream churned. After the addition of the wash water the churn was revolved 10 times in high gear, the rolls engaged, and the butter worked sufficiently in the wash water to bring the granules into a roll. The wash water was then drained and the working completed.

In addition to the usual churning records and the appearance of the butter over the trier, the data taken included the following items which require some amplification as to method.

1. **Hardness of the butter.**—This was determined using the method described by Coulter and Hill (2). The apparatus used is shown in Figure 5. The hardness values represent the grams of mercury required to crush ¾-inch cubes of butter to two-thirds of their original thickness. Differences in the diameter of the pulleys used give a mechanical advantage of 5. The cubes were prepared by tamping the fresh butter into brass forms of the proper size and holding for 24 hours at −17.78°C. (0°F.) in order that the butter could easily be removed from the forms. The cubes were then tempered in a water bath maintained at a constant temperature for 24 hours before being used for the hardness determinations. The temperature used for most of the work reported here was 10°C. (50°F.). However, some of the determinations were made at 8.89°C. (48°F.).

2. **Slicing time.** — This was determined as the time required in seconds for a known weight to pull the wires of a "Champion" butter cutter through a one-pound print of the butter. The weight used was either 50 or 75 pounds, depending on the firmness of the butter. The "Champion" butter cutter used has 13 cross wires and one longitudinal wire. The equipment used is shown in Figure 6. The butter after manufacture was held at 4.44°C. (40°F.) for 6 days and then held at 10°C. (50°F.) for 24 hours before making the slicing time determinations.

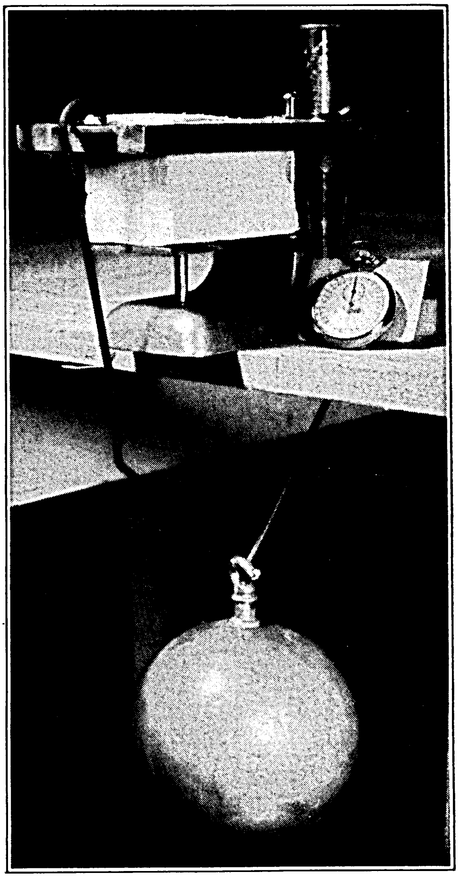

FIG. 6. APPARATUS USED FOR "SLICING TIME" DETERMINATIONS

3. **Standing-up properties of the butter.**—The ability of the butter to retain its shape when subjected to relatively high temperatures was determined by use of a method similar to that used by Leighton, Leviton, and Williams (16) for measuring the vis-

cosity of ice cream. Cylindrical beams were drawn from a print or tub of butter using a 13-millimeter cork borer. A rod fitted with a cork of suitable diameter was used to express the beam of butter from the cork borer. The butter beams were placed on racks as shown in Figure 7 and the whole placed in an oven thermostatically maintained at 26.67°C. (80°F.). The sag in millimeters was measured at 15-minute intervals by the use of a millimeter scale and a pair of dividers. The time in minutes for the butter beams to sag 5 millimeters was used as an indication of the standing-up properties of the butter. The butter in all cases was held at 4.44°C. (40°F.) for 7 days after manufacture before preparing the beams.

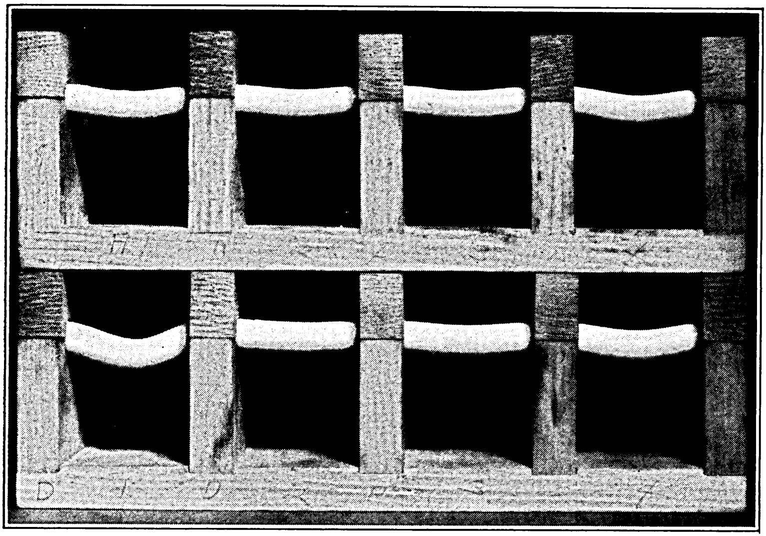

FIG. 7. APPARATUS USED FOR DETERMINING THE "STANDING-UP PROPERTIES" OF BUTTER

4. **Spreading qualities of the butter.**—The amount of pressure necessary to spread a portion of butter will doubtless vary directly with the hardness of the butter. The softer the butter, the easier it will spread. This, however, is not the sole indication of the desirability of butter for spreading. Whether the butter spreads smoothly, without crumbling, without curling, without sticking, can be determined perhaps only by actually spreading the butter. One and one-quarter inch cubes of the butter were placed on a glass surface and spread with a knife. In order that the angle of shear would always be the same, the passage of the knife was guided by two parallel sloping surfaces (Fig. 8) between which the glass slide containing the butter cube was placed. The

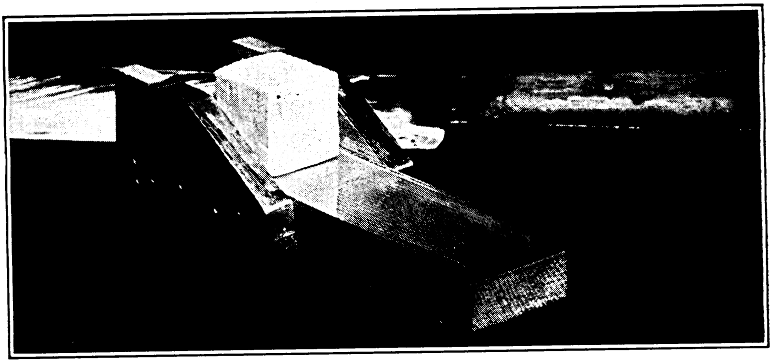

FIG. 8. APPARATUS USED FOR SPREADING BUTTER CUBES IN JUDGING THE SPREADING QUALITIES OF BUTTER

butter was held at 4.44°C. (40°F.) for seven days after manufacture before examining for spreading quality.

EXPERIMENTAL RESULTS

The Effect of Variation in the Churning Temperature

Different lots of the same cream were churned at 10°C. (50°F.) and at 15.56°C. (60°F.). Sufficient cream for eight churnings using the laboratory equipment was pasteurized, then cooled to 7.22°C. (45°F.) and held overnight at that temperature. One half of the cream was brought to 10°C. (50°F.) and the other half to 15.56°C. (60° F.) by warming in a water bath. Four churnings were made at each temperature. These churnings were washed with water at 15.56°C. (60°F.), 10°C. (50°F.), 4.44°C. (40°F.), and 0°C. (32°F.), respectively.

The hardness and slicing time of the butter from six series of these churnings are shown in Table 2. The standing-up properties of the butter as indicated by the time required for the beams to sag 5 millimeters when placed at 26.67°C. (80°F.) are shown in Table 3.

The butter from every churning with a churning temperature of 10°C. (50°F.) was harder than the corresponding churning at 15.56°C. (60°F.), and with two exceptions the slicing time of the 10°C. (50°F.) churnings was greater than that of the 15.56°C. (60°F.) churnings. In 16 of the 19 comparisons available the standing-up properties of the butter churned at 10°C. (50°F.) were greater than those of the butter churned at 15.56°C. (60°F.). The difference in the hardness values ranged from 26 to 214 grams. According to the data of Coulter and Hill (2), this is equivalent roughly to a change of from 0.5 to 4 units in the iodine number of the butterfat. These results are quite conclusive in indicating that the lower the churning temperature, the firmer

Table 2.—The Effect of Variation in the Temperature at which the Cream Is Churned, and of Variation in the Wash-water Temperature on the Hardness and Slicing Time of the Butter

Series	Iodine no. of butterfat	Churning temperature	Temperature of wash water—							
			15.56°C. (60°F.) hardness	15.56°C. (60°F.) slicing	10°C. (50°F.) hardness	10°C. (50°F.) slicing	4.44°C. (40°F.) hardness	4.44°C. (40°F.) slicing	0°C. (32°F.) hardness	0°C. (32°F.) slicing
Date		°C. (°F.)	grams	seconds	grams	seconds	grams	seconds	grams	seconds
5/14/35	....	10 (50)	946	58	929	70	927	73	868	46
		15.56 (60)	817	132	842	79	....	....	729	37
5/22/35	29.16	10 (50)	1320	too hard	1301	too hard	1223	480	1234	510
		15.56 (60)	1223	too hard	1199	158	1109	59	1050	38
5/28/35	33.61	10 (50)	854	182	881	88	848	43	826	29
		15.56 (60)	703	70	725	15	668	5	663	3
8/ 6/35	39.92	10 (50)	861	12.4	791	3	772	2.5	725	1.5
		15.56 (60)	772	3	738	1.6	676	1	672	0.5
8/20/35	....	10 (50)	738	160	734	105	710	61	723	61
		15.56 (60)	712	111	685	66	606	28	602	17
2/27/36	29.67	10 (50)	977	9.4	1037	6	988	4.5	976	3
		15.56 (60)	839	2.5	840	1.7	807	1	762	0.8

the butter produced and the greater the resistance of the butter to cutting and to deformation on warming.

Table 3.—The Effect of Variation in the Temperature at which the Cream Is Churned, and of Variation in the Wash-water Temperature on the Standing-up Properties of the Butter

Series	Churning temperature	Time required for beams to sag 5 millimeters with wash water of given temperature—			
		15.56°C. (60°F.)	10°C. (50°F.)	4.44°C. (40°F.)	0°C. (32°F.)
Date	°C. (°F.)	minutes	minutes	minutes	minutes
5/14/35	10 (50)	74	110	95	90
	15.56 (60)	85	85	.. ..	80
5/22/35	10 (50)	90	100	100	90
	15.56 (60)	25	35	35	25
8/ 6/35	10 (50)	33	45	45	38
	15.56 (60)	26	30	30	15
8/20/35	10 (50)	50	63	65	60
	15.56 (60)	60	60	50	49
2/27/36	10 (50)	105	105	90	67
	15.56 (60)	50	57	50	57

The effect of the difference in the churning temperature on the spreadability of the butter is shown by comparing the appearance of the spread butter cubes labeled "A" with those labeled "B" in Figures 9 and 10. Those labeled "A" were churned at 10°C. (50°F.), those labeled "B" at 15.56°C. (60°F.). In each group numbering from left to right the spreadings are from the butter washed at 15.56, 10.0, 4.44, and 0°C. (60, 50, 40, 32°F.), respectively. The butter shown in Figure 9 is from the series under date of 8/6/35, and in Figure 10, from the series under date of 2/27/36. The hardness values indicate that the butter from the 15.56°C. (60°F.) churnings would be easier to spread than the butter from the 10°C. (50°F.) churnings, and the spreading quality is somewhat more desirable, as shown by the appearance of the spread butter cubes in the illustration. When spread, the 10°C. (50°F.) churnings were more crumbly or friable. The marked improvement in the spreading appearance with decrease in the temperature of the wash water is clearly shown. The effect of the temperature of the wash water on the properties of the butter will be discussed in detail later.

The Effect of Variation in the Length of Time the Cream Is Held After Cooling

The hardness and slicing times of butter from cream held for various periods of time after cooling and washed with water at different temperatures are shown in Table 4. The standing-up properties of

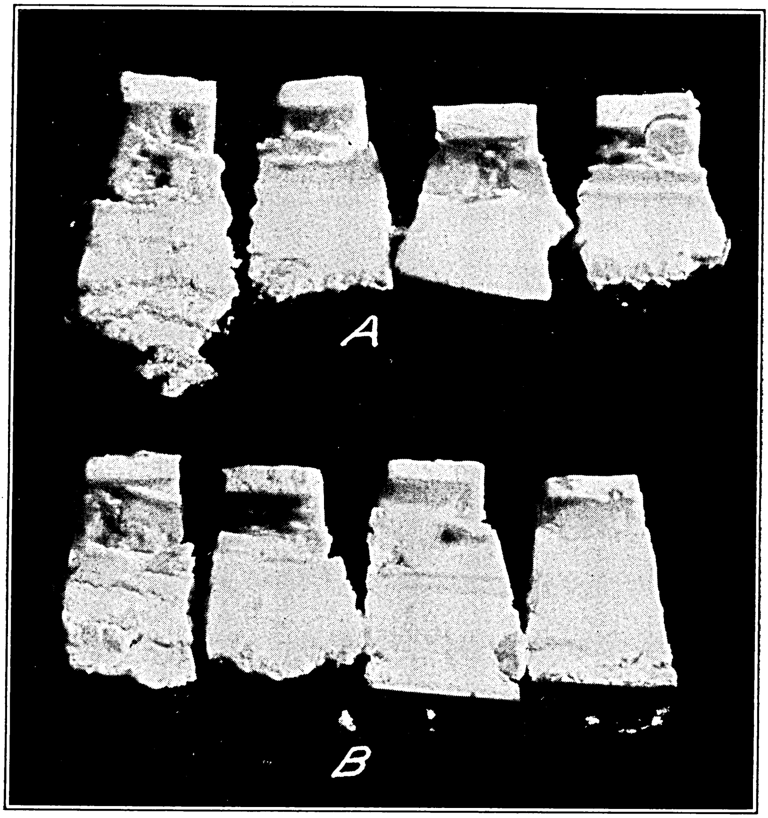

FIG. 9. SPREAD BUTTER CUBES FROM SERIES OF DATE 8/6/35
A. Churned at 10° C. (50° F.), cream held at 7.22° C. (45° F.) overnight.
B. Churned at 15.56° C. (60° F.), cream held at 7.22° C. (45° F.) overnight.

these butters are shown in Table 5. The churnings in each series in which the cream was churned immediately after cooling were made following the procedure recommended by Richardson and Abbott (14) for the prevention of sticky butter. The churning temperature of these churnings for the series of date 5/14/35 was 7.22°C. (45°F.). At this temperature the fat loss in the buttermilk was excessive, so the churning temperature was reduced to 1.67°C. (35°F.) for the same group of churnings in the next three series. The fat content of the buttermilk from these churnings was normal. In the last series, that under date of 2/27/36, the churning temperature for this group of churnings was raised to 7.22°C. (45°F.). In each series another group of churnings was made for which the cream was held for either one or three hours at the churning temperature before churning, and churned at 10°C. (50°F.). A third group of churnings in each series was made in which

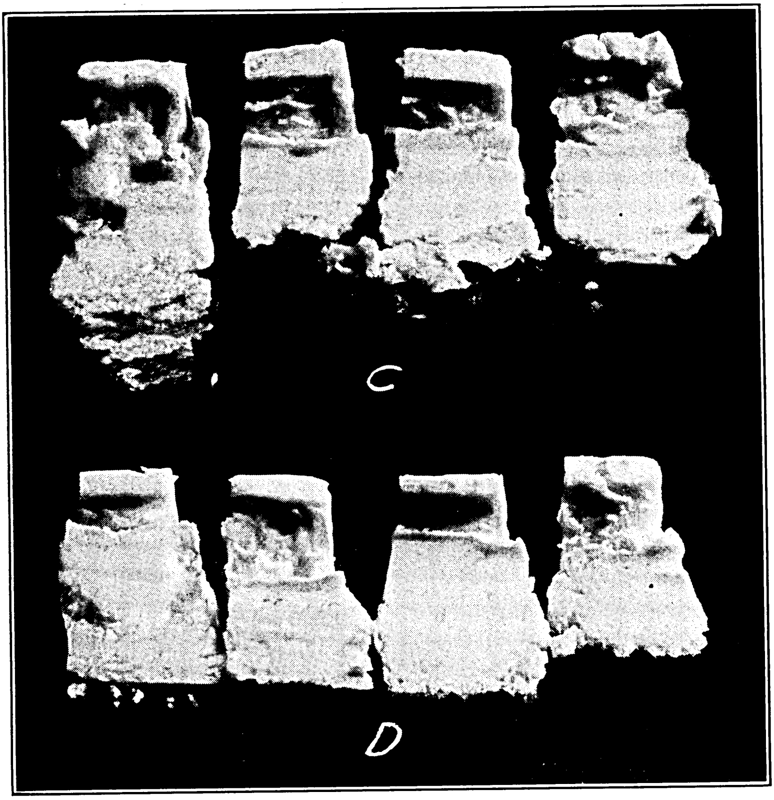

FIG. 9—Continued
C. Churned at 1.67° C. (35° F.), cream not held.
D. Churned at 10° C. (50° F.), cream held 3 hours at 10° C. (50° F.).

the cream was cooled to 7.22°C. (45°F.), held overnight, and churned at 10°C. (50°F.).

Omitting the data for the series under date of 5/14/35, the butter from the cream churned immediately after cooling was harder than the butter from the cream held overnight in 15 of the 16 comparisons, and harder than the butter from the cream held only 1 to 3 hours in 13 of the 16 comparisons. In every case the slicing time of the butter from the cream not held after cooling was greater than that of the butter from the other groups. In the series of date 5/14/35 the butter from the cream not held after cooling was softer than the butter from the other groups. As mentioned previously, however, the churning temperature of this cream was too high to permit normal churning.

There was no consistent difference in the hardness or slicing time of the butter from the cream held only one or three hours before churning

FIG. 10. SPREAD BUTTER CUBES FROM SERIES OF DATE 2/27/36
A. Churned at 10° C. (50° F.), cream held overnight at 7.22° C. (45° F.).
B. Churned at 15.56° C. (50° F.), cream held overnight at 7.22°C. (45° F.).

and that of the butter from the cream held overnight. In 8 of the 20 comparisons the butter from the cream held only one to three hours was harder and in 12 comparisons the butter from the cream held overnight was harder. The slicing time of the butter from the cream held overnight was greater in 7 of the 20 comparisons, and that of the butter from the cream held only one to three hours was greater in 13 of the 20 comparisons.

FIG. 10—Continued
C. Churned at 7.22° C. (45° F.), cream not held.
D. Churned at 10° C. (50° F.), cream held 3 hours at 7.22° C. (45° F.).

The standing-up properties of the butter from the cream held overnight were greater than those of the butter from the cream held only one to three hours. In all but two of the 16 comparisons the rate of sag of the beams from the butter from the cream held overnight was less, and in these two the rate of sag was the same. The standing-up properties of the butter from the cream not held were variable in comparison with those of the other butter. In the two series under date of 5/14/35 and

Table 4.—The Effect of Variation in the Length of Time the Cream Is Held at the Churning Temperature, and of Variation in the Wash-water Temperature on the Hardness and Slicing Time of the Butter

Series	Iodine no. of butterfat	Time held after cooling	Churning temperature	Temperature of wash water— 15.56°C. (60°F.) hardness	15.56°C. (60°F.) slicing	10°C. (50°F.) hardness	10°C. (50°F.) slicing	4.44°C. (40°F.) hardness	4.44°C. (40°F.) slicing	0°C. (32°F.) hardness	0°C. (32°F.) slicing
Date		hours	°C. (°F.)	grams	seconds	grams	seconds	grams	seconds	grams	seconds
5/14/35	....	16	10 (50)	946	58	929	70	927	73	868	46
		1	10 (50)	977	84	918	66	848	.....	819	40
		0	7.22 (45)	843	600	872	67	841	23	870	46
5/28/35	33.61	16	10 (50)	854	182	881	88	848	43	826	29
		1	10 (50)	978	78	1101	59	1130	50	1034	10
		0	1.67 (35)	1224	too hard	1141	300	1082	255	1194	190
8/ 6/35	39.92	16	10 (50)	861	12.4	791	3	772	2.5	725	1.5
		3	10 (50)	1016	13	846	3.5	788	2.2	671	0.5
		0	1.67 (35)	808	89	970	28	953	18	975	16
8/20/35	....	16	10 (50)	738	160	734	105	710	61	723	61
		1	10 (50)	696	226	717	235	715	124	685	84
		0	1.67 (35)	971	too hard	879	843	867	777	872	586
2/27/36	29.67	16	10 (50)	977	9.4	1037	6	988	4.5	976	3
		3	10 (50)	1148	28.0	1031	13	1002	6.5	984	5.7
		0	7.22 (45)	1112	180.0	1211	139	1104	24.5	1041	16

2/27/36, in which the cream was churned at 7.22°C. (45°F.), the rate of sag of the beams was greater than that of the butter churned from the cream held overnight. In the two series in which the cream was churned at 1.67°C. (35°F.) the rate of sag of the beams of this butter was almost the same as the rate of sag of the beams of the butter from the cream held overnight.

Table 5.—The Effect of Variation in the Length of Time the Cream Is Held at the Churning Temperature, and of Variation in the Wash-water Temperature on the Standing-up Properties of the Butter

Series	Time held at churning temperature	Churning temperature	Time required for beams to sag 5 millimeters, with wash water of given temperature— 15.56°C. (60°F.)	10°C. (50°F.)	4.44°C. (40°F)	0°C. (32°F.)
Date	hours	°C. (°F.)	minutes	minutes	minutes	minutes
5/14/35	16	10 (50)	74	110	95	90
	1	10 (50)	65	89	87	66
	0	7.22 (45)	25	32	80	64
8/ 6/35	16	10 (50)	33	45	45	38
	3	10 (50)	26	45	45	36
	0	1.67 (35)	39	45	50	40
8/20/35	16	10 (50)	50	63	65	60
	1	10 (50)	45	60	54	56
	0	1.67 (35)	62	60	65	60
2/27/36	16	10 (50)	105	105	90	67
	3	10 (50)	56	79	60	60
	0	7.22 (45)	66	80	80	57

The spreadability of the butter from the cream held only one to three hours, and especially that of the butter from the cream not held, was less desirable than that of the butter from the cream held overnight. The "spreadings" from the series under date of 8/6/35 are shown in Figure 9, and under date of 2/27/36 in Figure 10. The spreadings identified by the figure "A" are from the cream held overnight; those labeled "C", from the cream not held; those labeled "D", from the cream held one to three hours. In each group numbering from left to right the spreadings are from the butter washed at 15.56, 10, 4.44, and 0°C. (60, 50, 40, and 32°F.), respectively. The more crumbly, friable character of the butter from the cream not held is clearly shown. This is especially true of the spreadings in Figure 10, which are from the series under date of 2/27/36. The spreadability of the butter from the cream held one to three hours is superior to that of the butter from the cream not held, but not as good as that of the butter from the cream held overnight.

Table 6.—The Effect of Variation in the Temperature to which the Cream Is Cooled, and of Variation in the Wash-water Temperature on the Hardness and Slicing Time of the Butter

Series	Iodine no. of butterfat	Temperature to which cooled	Churning temperature	Temperature of wash water— 15.56°C. (60°F.) hardness	slicing	10°C. (50°F.) hardness	slicing	4.44°C. (40°F.) hardness	slicing	0°C. (32°F.) hardness	slicing
Date		°C. (°F.)	°C. (°F.)	grams	seconds	grams	seconds	grams	seconds	grams	seconds
12/19/35	....	15.56 (60)	15.56 (60)	817	12.0	810	2.2	721	1.2	703	1.0
		4.44 (40)	15.56 (60)	1010	53.0	947	3.1	922	1.1	828	2.0
12/31/35	....	10 (50)	10 (50)	728	1.8	702	2.0	....	......	585	1.2
		10 (40)	10 (50)	....	....	848	9.6	....	......	796	6.0
2/ 5/36	30.78	11.1 (52)	11.1 (52)	....	....	....	......	707†	0.3†	....	......
Large		11.1 (52)	11.1 (52)	....	....	....	......	760	1.0	....	......
churn		4.44 (40)	11.1 (52)	....	....	897*	3.0*	....	......	....	......
2/ 8/36	29.67	11.1 (52)	11.1 (52)	....	....	....	......	675	1.3	....	......
Large		4.44 (40)	11.1 (52)	....	....	....	......	823†	6.2†	....	......
churn		4.44 (40)	11.1 (52)	....	....	812*	5.8*	....	......	....	......

* Washed at 56°F.
† Washed at 38°F.

The Effect of Variation in the Temperature to Which the Cream Is Cooled

Different lots of the same cream tho churned at the same temperature were cooled to, and held overnight at, temperatures differing by at least 5.55°C. or 10°F. One lot of the cream in each series was cooled to 4.44°C. (40°F.). The other lot was cooled only to 10, 11.1, or 15.56°C. (50, 52, or 60°F.). The cream cooled to, and held at, the lower temperature was warmed to the same temperature as that of the other for churning. Wash water at various temperatures was used. The hardness and slicing time of the resulting butter are shown in Table 6 and the standing-up properties of the butter in Table 7.

Table 7.—The Effect of Variation in the Temperature to Which the Cream Is Cooled, and of Variation in the Wash-water Temperature on the Standing-up Properties of the Butter

Series	Temperature to which cooled	Churning temperature	Time required for beams to sag 5 millimeters with wash water of given temperature— 15.56°C. (60°F.)	10°C. (50°F.)	4.44°C. (40°F.)	0°C. (32°F.)
Date	°C. (°F.)	°C. (°F.)	minutes	minutes	minutes	minutes
12/19/35	15.56 (60)	15.56 (60)	27	33	24	18
	4.44 (40)	15.56 (60)	65	52	50	48
12/31/35	10 (50)	10 (50)	85	67	......	45
	4.44 (40)	10 (50)	105	. .	......	105

Cooling of the cream to the lower temperature produced a marked increase in the firmness of the butter. This increase ranged from 125 to 211 grams for the butter from these churnings. The slicing time of the butter in all except one of the comparisons was greater for the butter from the low-cooled cream, and in every case the standing-up properties of the butter from the low-cooled cream were greater.

There was a distinct difference in the spreadability of the butter. The spread cubes of butter from the series of date 12/19/35 are shown in Figure 11. The group labeled "A" are from the cream cooled only to 15.56°C. (60°F.), and the group labeled "B" from the cream cooled to 4.44°C. (40°F.) and churned at 15.56°C. (60°F.). The small figures 1, 2, 3, and 4 indicate that the butter was washed at 15.56, 10, 4.44, and 0°C. (60, 50, 40, and 32° F.), respectively. The spreading qualities of the butter from the cream cooled only to 15.56°C. (60°F.) were definitely superior to those of the butter from the cream cooled to 4.44°C. (40°F.). This is especially apparent in the butter washed with water at 4.44 and 0°C. (40 and 32°F.). The butter from the cream cooled only to 15.56°C. (60°F.) and washed at 4.44 and 0°C. (40 and 32°F.) ex-

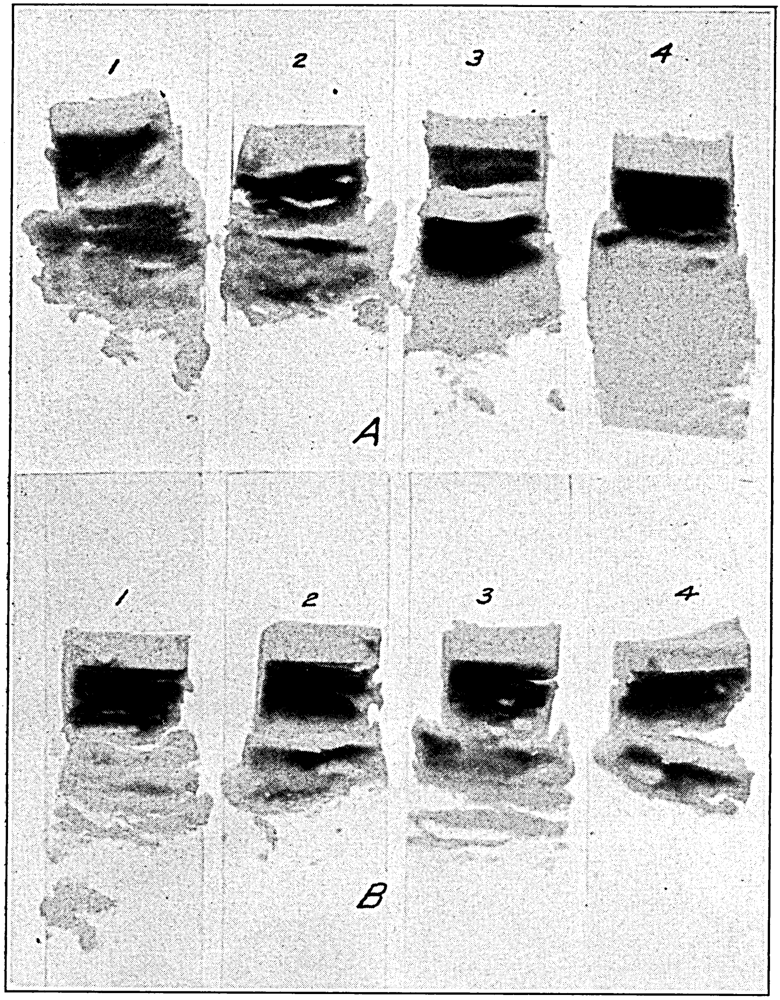

FIG. 11. SPREAD BUTTER CUBES FROM SERIES OF DATE 12/19/35

A. Cream cooled to 15.56° C. (60° F.), held overnight and churned at 15.56° C. 60° F.).

B. Cream cooled to 4.44° C. (40° F.), held overnight and churned at 15.56° C. (60° F.).

hibited excellent spreading properties, while that from the cream cooled to 4.44°C. (40°F.) was somewhat brittle and crumbly. There is thus some indication that, with winter butterfat, the improvement which it is possible to secure in the body of the butter by the use of cold wash water is minimized if the cream is cooled excessively.

These data show that a definite improvement in the body of winter butter can be effected by avoiding excessive cooling of the cream. By cooling only to, or slightly lower than, the churning temperature (10 or 11.1°C. [50 or 52°F.]) and holding at that temperature instead of cooling to 4.44°C. (40°F.), holding overnight, and warming to the churning temperature the next day, a decrease in butter hardness of 125 to 211 grams resulted. This is equivalent, according to the data of Coulter and Hill (2), to an increase of 2.5 to 4 units in the iodine number of the butterfat. Conversely, during summer when the iodine number of the butterfat is high and the butter naturally soft, cooling the cream to a low temperature should be practiced in order to secure butter as firm as possible.

The Effect of Variation in the Rate of Cooling

The hardness and slicing time of butter from cream cooled over a surface cooler, and of butter from separate batches of the same cream cooled in a vat, are shown in Table 8. Both lots of cream were cooled to 7.22°C. (45°F.), and held overnight before churning. The churning temperature for all churnings was 10°C. (50°F.). The butter from the cream cooled over the the surface cooler was harder and the slicing time longer than that from the vat-cooled cream. This was true irrespective of the wash water temperature used. The differences were not great, but indicate that if butter with the most desirable body is to be produced during the winter, cooling the cream to a low temperature over a surface cooler should be avoided.

Table 8.—The Effect of Variation in the Rate at Which the Cream Is Cooled, and of Variation in theWash-water Temperature on the Hardness and Slicing Time of the Butter

Series	Iodine no. of butter-fat	Method of cooling	Temperature of wash water—							
			15.56°C. (60°F.) hard-ness	slic-ing	10°C. (50°F.) hard-ness	slic-ing	4.44°C. (40°F.) hard-ness	slic-ing	0°C. (32°F.) hard-ness	slic-ing
Date			grams	seconds	grams	seconds	grams	seconds	grams	seconds
10/12/35	30.60	Surface cooler	1088	97	1061	80	1029	68	978	65
		Vat	1000	77	1028	46	947	36	936	33

The Effect of Variation in the Temperature of the Wash Water

Data relative to the influence of variation in the temperature of the wash water on the hardness and slicing time of the butter are included in Tables 2, 4, 6, and 8 and on the standing-up properties of the butter in Tables 3, 5, and 7.

Comparing the hardness of any one lot of butter with the hardness of the butter from all other churnings of the same cream, churned under the same conditions but washed at a lower temperature, in 133 or 83.1

per cent of the 160 comparisons available the use of colder wash water resulted in butter of lesser hardness. In a similar comparison of the slicing time, the use of colder wash water produced butter with a shorter slicing time in 149 or 93.7 per cent of the 159 comparisons available. The reduction in the hardness of the butter with decrease in the temperature of the wash water is quite uniform through the temperature range used (15.56 to 0°C. [60 to 32°F.]). The average hardness of the butter washed at 15.56°C. (60°F.) was 945 grams; of that washed at 10°C. (50°F.), 935 grams; of that washed at 4.44°C. (40°F.), 891 grams; and of that washed at 0°C. (32°F.), 868 grams.

The effect of variation in the wash water temperature on the standing-up properties of the butter was not strictly uniform, tho the data indicate that butter with the greatest resistance to deformation on warming is produced by the use of wash water neither excessively warm nor excessively cold. The beams showing the greatest rate of sag or a rate of sag as great as any other beam in the same series were from the butter washed at 15.56°C. (60°F.) in 15 of the 22 comparisons, from the butter washed at 0°C. (32°F.) in 13 comparisons, and from the butter washed at 10 and 4.44°C. (50 and 40°F.) only once each in the 22 comparisons. Similarly, the beams showing the slowest rate of sag or a rate of sag not faster than that of any other beam in the same series were from the butter washed at 10°C. (50°F.) in 18 instances, from the butter washed at 4.44°C. (40°F.) in 12 instances, and from the butter washed at 15.56 and 0°C. (60 and 32°F.), in 7 and 2 comparisons, respectively.

The spreadability of the butter was markedly influenced by the temperature of the wash water. The lower the temperature of the wash water, the less hard the butter and consequently the easier the butter was to spread. Also, the lower the temperature of the wash water, the more desirable the manner of spreading. The spread butter cubes of the series dated 8/6/35 are shown in Figure 9; of the series dated 12/18/35, in Figure 11, and of the series dated 2/27/36, in Figure 10. These illustrations show clearly the improvement in the spreadability of the butter with decrease in the temperature of the wash water. The lower the temperature of the wash water, the less sticky, more pliable, and less crumbly or friable the spread.

The appearance of the butter over the trier was in general improved by the use of low-temperature wash water. The butter washed at 15.56°C. (60°F.), and to a lesser degree that washed at 10°C. (50°F.), appeared over the trier to have a sticky crumbly body. This was especially true of the winter butter. The butter washed at the lower temperatures had a finer grain and was much less sticky and less crumbly

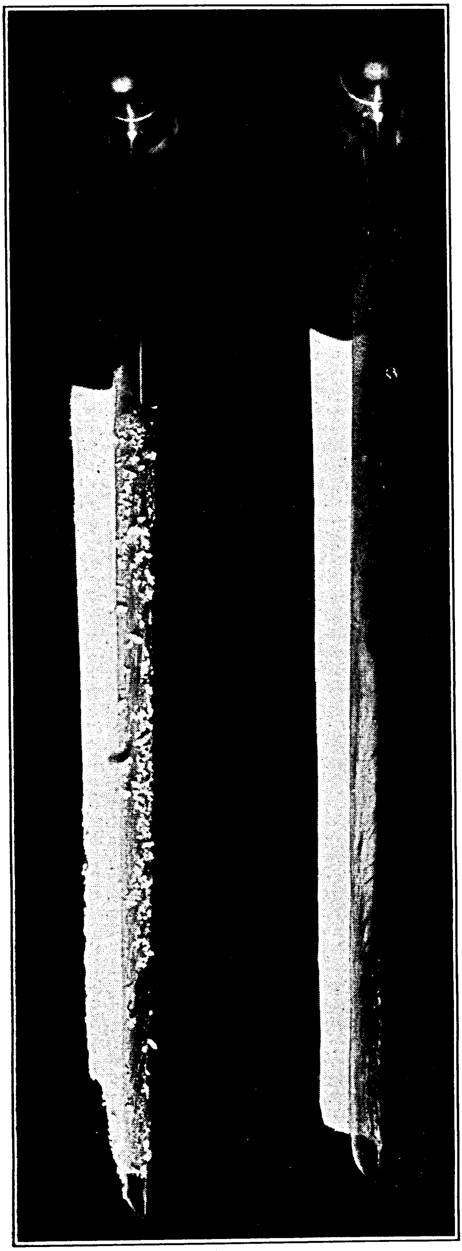

FIG. 12. APPEARANCE OF TRIERS DRAWN FROM BUTTER WASHED WITH WATER AT DIFFERENT TEMPERATURES

The butter from which the trier on the left was drawn was washed with water at 13.89°C. (57°F.) while the butter from which the trier on the right was drawn was washed with water at 6.67°C. (44°F.).

or friable. The improvement which it is possible to secure in the appearance of the butter over the trier by the use of low-temperature wash water is illustrated in Figure 12. The butter from which the trier to the left in the photograph was drawn was churned from cream cooled to 10.55°C. (51°F.), held overnight, and churned at 14.44°C. (58°F.). The butter was washed with water at 13.89°C. (57°F.). The butter from which the trier to the right was drawn was churned in the same creamery, on the same day (April 2, 1936), and under the same conditions except that the butter was washed with water at 6.67°C. (44°F.). The iodine number of the butterfat from a composite sample of the butter was 29.89.

It will be observed, as has been mentioned previously, that the extent to which the cream was cooled before churning influences the character of the butter. With winter butter, the use of low-temperature wash water may not eliminate the sticky, crumbly character if the cream has been cooled to an excessively low temperature before churning. From the standpoint of avoiding sticky, crumbly butter, the lower the temperature of the wash water the better. This is somewhat offset, however, by the fact that the body of the butter washed at 0°C. (32°F.) resembled suet. The color of this butter was lighter and lacked luster as compared with the butter washed at a higher temperature. The use of wash water at such an extremely low temperature is probably not desirable, and even if desirable would not be practical in most creameries.

The results secured in this work are in essential agreement with those secured by Mohr and Oldenburg (10), Wode (8), and Storgard (11). These investigators all found that the lower the temperature to which the cream was cooled the harder the butter. The use of low-temperature wash water was found by all to reduce the hardness of butter made from butterfat with a low iodine number. This effect was minimized by Wode, and found by him to be reversed with butter from butterfat with a high iodine number. Storgard found the effect to be slight only with butter from butterfat with a high iodine number. Mohr and Oldenberg did not discriminate in this effect between summer and winter butter. In the present work the effect of the temperature of the wash water was found to be as great with winter butter as with summer butter, except when the cream from which the winter butter was churned was cooled excessively. The results of Richardson and Abbott (14) are not strictly comparable. Their recommendation that the cream be cooled rapidly to a temperature 8 to 10°F. below the normal churning temperature and churned immediately was designed to prevent excessive crystallization of the fat. The present work and also that of Mohr and Oldenburg (10), Wode (8), and Storgard (11) would indicate that the same result could be secured with cream to be held for some hours by cooling it only to the churning temperature. The results secured in this work were more satisfactory when this procedure was followed. The facilities and routine for handling the cream in the plant would perhaps dictate the method to be followed. In either case rapid cooling particularly over a surface cooler should be avoided.

APPLICATION OF THE RESULTS TO PRACTICAL BUTTERMAKING

The Manufacture of Winter Butter

The following recommendations should apply to the manufacture of butter from butterfat with a low iodine number. Practically all butterfat produced in the Northwest during the period from December 1 to March 1 will have an iodine number of 31 or less. These recommendations can be followed with advantage during this period and to a greater or less degree for a time both before and after this period depending upon the character of the butterfat received and the butter body desired.

1. The wash water for the butter should be cooled to 4.4°C. (40°F.). To cool the wash water to a lower temperature than 4.4°C. (40°F.) would seldom be practical and might not always be desirable. The body of the butter, however, will be improved by cooling the wash water at least to 4.4°C. (40°F.). Where wash water this cold is used, the water should be left in contact with the butter for a sufficient time to chill the granules thoroly. In some instances ragged boring butter was produced when the wash water was added, the churn revolved 10 revolutions in high gear, and the water drained immediately. This doubtless was due to the fact that the butter granules were not uniformly chilled. In this work, as indicated in the discussion of the experimental methods, the laboratory churnings were washed twice with wash water of the desired temperature, leaving each portion of the wash water in contact with the butter for five minutes. In the commercial churnings, the granules were washed as usual and then worked sufficiently in the wash water to gather the granules into a roll.

Some buttermakers have objected to the use of cold wash water because of the increased firmness of the butter when removed from the churn. The butter at this stage will be somewhat firmer than if wash water at 12.22 to 15.56°C. (54 to 60°F.) had been used, as is the common procedure. If the butter has been properly worked, however, it may be handled easily. Since the butter is firm, it will require considerable more working than if warmer wash water had been used.

2. Excessive cooling of the cream should be avoided. The cream, if it is to be held over night, should be cooled only to the churning temperature or slightly lower and held at that temperature.

3. The churning temperature used should not be lower than the temperature necessary to secure exhaustive churning under normal churning conditions. Normal churning conditions may be defined as the operation of the churn at standard speed for the churn used, with the churn not more than half full of cream of average richness (25 to 35 per cent butterfat). A churning time of 30 to 45 minutes should be sufficient to secure exhaustive churning with winter cream under these conditions.

4. Where a surface cooler is used, rapid cooling should be avoided. The data are incomplete in this respect. However, the results available indicate that if the cream is cooled to a low temperature (4.4°C. [40°F.] or under) over a surface cooler, the butter will be firmer than if the cream was vat-cooled. This should logically be true to some extent also for cream cooled only to 10 to 15.56°C. (50 to 60°F.) over a surface cooler.

The Manufacture of Summer Butter

The following recommendations should apply to the manufacture of butter from butterfat with a high iodine number. Under normal feeding conditions, butterfat produced in the Northwest during the period from June 1 to September 1 will have an iodine number of 38 or above. These recommendations can be used with advantage to improve the body of butter during this period.

1. Since the body of summer butter is normally soft, a relatively high wash-water temperature should be used. Tho wash water with a temperature as high as 15.56°C. (60°F.) will increase the firmness of the butter, wash water this warm will reduce the standing-up properties of the butter. It is probable that the optimum temperature of the wash water will be about 10°C. (50°F.).

2. The cream should be cooled to and held at as low a temperature as is practical. Cooling of the cream to a low temperature will increase the firmness of the butter and also increase the standing-up properties of the butter.

3. The cream should be churned at as low a temperature as is practical. The lower the churning temperature, the greater the hardness of the butter.

THEORETICAL INTERPRETATION OF THE RESULTS

Wode (8), Mohr and Oldenburg (10), Storgard (11), and Richardson and Abbott (14), all present theoretical discussions to substantiate their results. To present and compare in detail the theories presented would be too lengthy a discussion. A brief review together with a presentation of the views held by the authors will be given.

That the fat in cream at the churning temperature is partially crystalline and partially liquid has been accepted since the work of Van Dam (17). Obviously the lower the temperature, the more complete the degree of crystallization. That this partial crystallization is possible is due to the fact that butterfat is a mixture of mixed glycerides. Tho most of the butterfat glycerides will crystallize at much higher temperatures, Arup (18) has shown that it is possible to obtain by fractional crystallization a butterfat fraction still liquid at 10°C. (50°F.). Van Dam and Burgers (19) by X-ray examination have shown the presence of liquid fat in butter. The proportion of low-melting-point glycerides will vary with the proportion in which the various fatty acids occur in the butterfat. A high proportion of oleic acid or of other unsaturated fatty acids or a high proportion of the volatile fatty acids should logically increase the proportion of the low-melting-point glycerides.

Wode (8) suggests that the temperature to which the cream is cooled and also the rate of cooling may influence not only the proportion of crystalline fat, but also the size of the fat crystals. This would follow from the known principle of crystallization that the lower the temperature below the saturation point, the smaller the crystals formed. This fact can readily be demonstrated in butterfat in mass, and so can be assumed to occur in butterfat in the fat globule. The liquid fat fraction will drain much more rapidly from butterfat crystallized slowly than from butterfat crystallized rapidly, since the fat crystals are larger. This was shown by Wode (8) and has been verified in the Minnesota laboratory. Five paper cups were filled with butterfat from the same lot. These cups were then placed, one each at 21.1, 15.56, 10, 4.44, and —23.3°C. (70, 60, 50, 40, and —10°F.) for 24 hours for the fat to crystallize. All portions were then placed at 7.2°C. (45°F.) for 24 hours, following which the butterfat from each was placed over filter paper in an incubator maintained at 26.67°C. (80°F.). The filtrate was collected in graduated cylinders. The volume of filtrate from each portion as measured at intervals during seven hours is shown below:

Time after placing at 26.67°C. (80°F.)	Milliliters of filtrate from fat crystallized at—				
	21.1°C. (70°F.)	15.56°C. (60°F.)	10°C. (50°F.)	4.44°C. (40°F.)	—23.3°C. (—10°F.)
Hours	ml.	ml.	ml.	ml.	ml.
1½	8	5	0	0	0
3½	12	9	5	4	3
5	16	13	9	7	6
7	16	14	12	11	10

Whether a similar difference exists in the rate with which the liquid fat fraction will drain from rapidly and slowly crystallized butterfat in the fat globule can only be postulated. If true it offers, as Wode (8) has suggested, an explanation for the effect of the rate of cooling and extent of cooling of the cream on the hardness of the butter. The total amount of liquid fat in butter will depend upon the temperature at which the butter is held, and upon the proportion of low-melting-point glycerides. Following the concept of butter structure as proposed by King (20), Wode distinguished between the fat held in the fat globules and the free fat. According to Wode, the smaller amount of free fat, the harder the butter. The proportion of liquid fat in the fat globules at the time of churning would depend upon the thoroness with which the cream had been cooled, and upon the proportion of low-melting-point glycerides in the butterfat. From this concept of butter structure, the amount of free fat produced in the butter at the time of churning and working should depend upon the proportion of liquid fat in the fat globules and upon the ease with which the liquid fat can drain from the fat globules. Thus, thoro cooling of the cream would decrease the amount of free fat in the butter. Rapid cooling of the cream as compared with slow cooling, together with cooling to a low temperature, would decrease the size of the fat crystals in the fat globules, thus decreasing the ease with which the liquid fat can drain from the fat globules and so also decreasing the amount of free fat in the butter.

Storgard (11) while presenting the same theory with regard to the formation of "free" fat in butter emphasizes the importance of the working of the butter. He contends that the greater the amount of working and the softer the butter, the greater the amount of free fat formed. This is due to the break-down of the fat globules and mixing of their contents with the continuous fat mass. The continuous fat phase would thus be increased and its characteristics altered.

The possibility that variation in the rate of crystallization of the liquid fat in the butter could affect the hardness of the butter was largely neglected by Wode (8) and Storgard (11). Mohr and Oldenburg (10), on the other hand, stress the importance of this factor. That this crystallization does take place is evidenced by the firming of the butter following working and by the formation of a macroscopic crystalline structure in the butter during this period. Following working, butter normally is more or less salvy and appears to the eye to be essentially amorphous. Butter normally, however, hardens rapidly and soon has a definite crystalline structure. Butter with a desirable body is frequently said to break in such a manner that the appearance of the broken surface is compared to that of broken iron.

As previously shown, the lower the temperature below the crystallization point, the smaller the crystals formed. Thus, as indicated by Mohr and Oldenburg (10), the use of cold wash water can be expected to produce butter in which the fat crystals from the butterfat crystallizing after churning are smaller than in butter washed with warm wash water. The coarser the crystalline structure, the firmer will be the butter. Van Dam and Burgers (19) were not able to detect by X-ray examination any marked difference in the size of the fat crystals in butter washed with water at 3.6°C. (38.48°F.) and in butter washed with water at 13°C. (55.4°F.). They concluded that the marked difference in the structure of the butters could not be ascribed exclusively to a difference in crystal size.

The above concepts are not in agreement with the opinions of Richardson and Abbott (14). In explaining the results secured by them in handling butterfat from cows on a sole diet of alfalfa hay they say: "When cream containing this type of fat is handled in the manner common to normal churning procedure, an excessive proportion of the fat has crystallized at the time of churning. Too small a portion remains homogeneous to give the resulting butter the coherence and tenacity necessary for plasticity or spreading ability. When such cream is rapidly cooled from a temperature at which the fat is liquid to the proper temperature for churning, and churning is commenced without delay, the fat at the time of churning is a solidified, more or less homogeneous mass, with a decreased tendency to separate into liquid and crystalline portions." These statements are not compatible with the theories hereinbefore expressed. The fat liquid in the butter at the time of churning can not all be expected to remain homogeneous. In fact, it must be this fat, its amount and its manner of crystallization, which determines largely the character of the butter texture.

The concepts presented serve to explain the effect of the use of low-temperature wash water and the avoidance of rapid and excessive cooling of the cream on the hardness and gross crystalline structure of winter butter. They do not, however, explain the effect of these practices in reducing the tendency toward stickiness.

Overworking and Sticky Butter

Overworking has long been recognized as a condition producing sticky butter. Every buttermaker is familiar with the fact that the

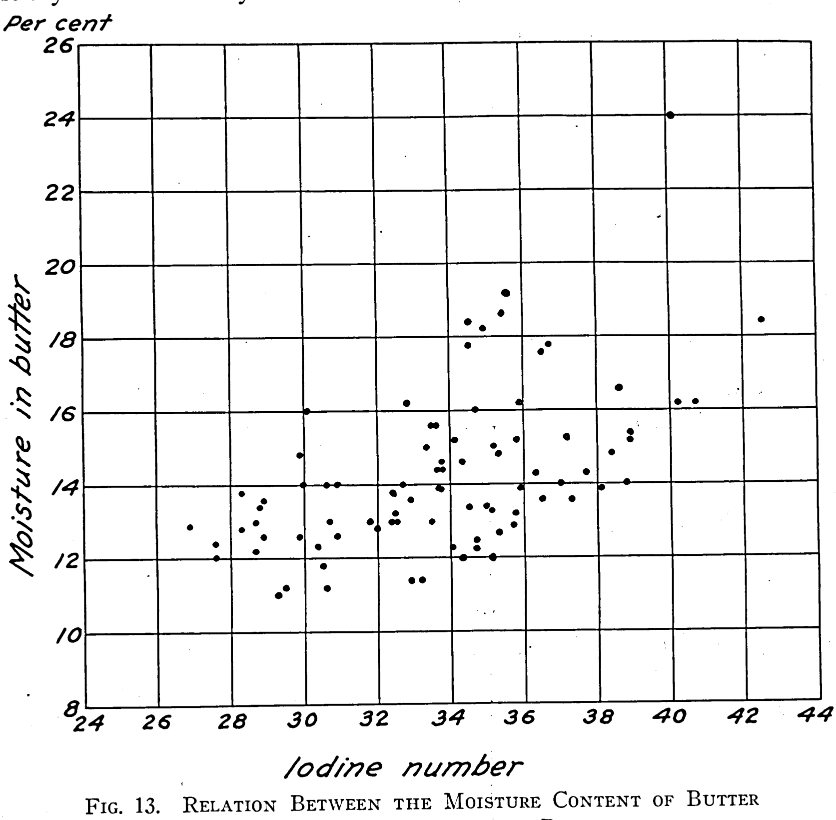

FIG. 13. RELATION BETWEEN THE MOISTURE CONTENT OF BUTTER AND THE IODINE NUMBER OF THE BUTTERFAT

softer the butter, the more easily it may be overworked. Efficient workmanship requires that approximately 16 per cent moisture be incorporated in the butter. The natural water-retaining capacity of summer butter is somewhat greater than that of winter butter. This fact was shown by Hunziker and co-workers (21), who attributed it to the greater softness of the summer butter, due in turn to the higher iodine number of the summer butterfat. Palmer (22) suggested that the water-retaining capacity of butter was associated directly with the iodine number of the butterfat. Extensive data showing the relationship between the iodine number of the butterfat and the water-retaining capacity of the butter were reported by Coulter and Hill (2). A summary of this data is shown in Figure 13. All churnings were made under similar conditions, and the butter was worked uniformly and in such a manner that all surplus water could drain away. The correlation coefficient between the per cent of moisture in the butter and the iodine number of the butterfat was +0.55.

Owing to the greater natural water-retaining capacity of the summer butter, winter butter would require more working to incorporate the additional moisture needed to secure 16 per cent moisture in the butter. The use of cold wash water to firm the butter before working would not reduce the amount of moisture retained in the butter granules, but would reduce the danger of overworking, due to the greater firmness of the butter at the time of working.

The fundamental reasons for the effect of overworking on the body of butter can probably only be postulated. Butter naturally adheres to the metal with which it comes in contact. Passage of a trier through butter is doubtless facilitated by lubrication with water or liquid fat or both. In normal-bodied butter both liquid fat and water probably assist in permitting a smooth bore to be drawn. The more the butter is worked, the finer the distribution of the water, and, consequently, the less free water available for lubricating the passage of the trier. That this is not the sole factor involved, however, is evidenced by the fact that many samples of butter are found from which a smooth bore cannot be drawn despite the presence of much free water. Storgard (11) theorized that overworking changed the composition of the continuous fat phase in butter by breaking down the fat globules and mixing their contents with the continuous phase. If it is admitted that the continuous fat phase is composed of the lower-melting-point glycerides, and the presence of a continuous fat phase can only be accounted for on this basis, it seems plausible that overworking would alter the composition of the continuous fat phase in the manner suggested. Certainly the more liquid the continuous fat phase, the greater the ease with which the